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# Marine Physical Laboratory

## Analysis of Sperm Whale Acoustic Signals in the Gulf of Mexico and th Mediterranean

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## **Final Report: automated 3D tracking of sperm whales using towed arrays**

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### **LONG-TERM GOALS**

My long-term goal is to produce a passive method for identifying potential effects of seismic and other anthropogenic noise on sperm whale dive times and maximum dive depths. This information, in turn, will be of use in developing models of the foraging costs associated with long-term exposures to low-level anthropogenic sounds. The method complements current tagging studies, and would also provides a means for checking what, if any, effect a tag may have on an animal's baseline diving behavior.

### **OBJECTIVES**

My objective is to develop and demonstrate an automated procedure for passively tracking sperm whales in three-dimensions, using natural vocalizations recorded on two towed arrays, deployed either alone or in conjunction with dive tags. The algorithms would permit automated tracking of multiple animals over complete dive cycles, producing statistically significant sample sizes for evaluation of controlled-exposure studies. When used in conjunction with a dive tag, the algorithm would permit better resolution tracking of animals detected on both the tag in array, effectively "leveraging" the tag's utility.

### **APPROACH**

Previous work by the PI[1] has shown that 3D tracking of sperm whales is possible using a single towed array, using multipath reflections from the ocean surface and bottom. However, the resulting algorithm was difficult to automate and required substantial effort by a human, yielding only one 3D trajectory per ten hours of work. In addition, the bottom returns were detected only sporadically, during times when the animals were in their initial descent to presumed foraging depth. During feeding and/or social behavior the bottom returns are usually absent.

To overcome these difficulties, a new algorithm has been developed, using two spatially-separated towed arrays deployed serially from a single vessel to record both the direct and surface reflections of sounds. The automated detection and classification of direct and surface paths is considerably simpler than that required for bottom returns, but requires information about the array depths to be effective. The results would have lower depth resolution than those obtained using bottom returns, but could be computed automatically, reducing the processing time to an estimated 15 minutes per trajectory. Thus the technique is designed to produce large numbers of low-resolution tracks, as opposed to a single high-resolution track generated by an tagged animal.

If one of the animals present has an acoustic tag(e.g. [2]), the algorithm can be extended to time-sync the tag with the array record, effectively creating a large-aperture array. This approach would provide much more precise localizations of all animals, at the cost of requiring a tagged animal to be present.

## **WORK COMPLETED**

The localization algorithms have been written and tested in simulation. The automated data extraction algorithms have been written using both MATLAB and the software package Ishmael[3] (written by David Mellinger of Oregon State University under ONR support). The algorithms have been applied to acoustic data collected during July 2001 in the Gulf of Mexico, as part of the SWAMP 2001 experiment conducted jointly by the Minerals Management Service and National Marine Fisheries Service. The ability to extract all the data needed for localization was demonstrated. It was also found that a tagged whale can be identified on the array recordings amongst several other vocalizing animals, and that the acoustic record on the tag could therefore be time-synched with the array records, and it was determined that four other animals could have been tracked at one time.

Unfortunately, the arrays used during 2001 did not have depth sensors attached to them. An unsuccessful attempt was made to invert for whale and array positions simultaneously using the extracted data, leading to the conclusion that a robust algorithm requires auxiliary array depth information, in addition to the acoustic data. Work will continue on trying to localize animals on the 2001 data set during the latter half of 2002. Preparations are currently underway for the 2002 SWSS DTAG Cruise in the Gulf of Mexico, which will include two towed arrays with depth sensor information. During the cruise the localization procedure will be tested using data collected during the night, under both baseline and controlled exposure conditions.

## **RESULTS-TOWED ARRAYS ONLY**

Data analysis illustrating the feasibility of the algorithm is presented here. To first illustrate the concept using towed arrays only, acoustic data recorded at 3:39 AM on July 28, 2001 have been used. During this time two arrays were taped together in series to produce a single long cable with a separation of 312 m between the front-end elements. The ship cruised next to a group of sperm whales in the Mississippi Canyon area (29.0890 N; -88.0890 W), whilst a seismic vessel was conducting operations 5 km away.

Figure 1 illustrates the array bearings of four whales over a twenty-minute period, recorded on both arrays. When a track on one array is selected, the MATLAB routines identify the corresponding track on the second array, extract the sounds associated with the array tracks, identify associated surface reflections, and compute the difference in arrival times between the direct and surface arrivals for each array, as well as the difference in arrival times between direct paths on both arrays. This information, coupled with knowledge of the array depths, is sufficient to obtain the depth and range of the animal. Incorporation of bearing information gives the true azimuth. Figure 2 illustrates the resulting intermediate output for three whales, after five minutes of processing. Whale 1 is passed by the ship midway through the sequence, while Whales 2 and 3 always remain ahead of the ship. With knowledge of the array depth the time-of-arrival (TOA) information shown here can easily be converted into a trajectory.

## **RESULTS-MATCHING TAG DATA WITH TOWED ARRAYS**

Data have also been analyzed from July 19, 2002, 18:01 PM, when an acoustic tag developed by Mark Johnson and Peter Tyack of the Woods Hole Oceanographic Institution (WHOI) was deployed on a whale. During this time two arrays were also deployed off the back of the Gunter. The WHOI group provided 40 minutes of data to test whether the acoustic data on the tag could be coordinated with the array acoustic data.

With a slight modification of the extraction algorithm, the sounds of untagged whales on both the tag and arrays can be identified and matched. Once again, if the array depths were known, the position of the tagged whale relative to the array could be derived, the relative arrival times of the other whales' sounds on the tag and array could be determined precisely, and enough information would exist to localize all vocalizing animals.

To illustrate this idea Figures 3-4 show how the tagged whale was located and identified on the array data, and Figure 5 shows how the tagged whale could in principle be used to track four other untagged whales in the area. Figure 3, like Figure 1, shows the bearings of multiple animals vs. time. During this time the ship course and speed changed rapidly, and thus the bearing tracks have an unusual appearance. Up to six whales are present at any given time. The track that eventually was found to be the tagged whale is labeled and marked in red. The other two tracks are whales that seem to be associated with the tagged animal.

In order to automatically identify which animal on the array was the tagged animal, each bearing track was selected and the interval between each successive sound, or the inter-click interval (ICI), was extracted along with the other multipath information. Then the extraction algorithm was run on the acoustic tag record, but the sensitivity of the Ishmael detection algorithm was set to detect only high-amplitude sounds, those most likely to be associated with the tagged whale itself. A crude cross-correlation test easily determined which ICI pattern best fit with the tagged whale, and is shown in Figure 4.

Other sounds were detected on the acoustic tag as well, and Ishmael was re-run a second time with higher sensitivity to detect all sounds. When the extraction algorithm was run a second time, a sound from the same untagged animal could be identified on both the array and tag, and the relative arrival times of the sounds between tag and array computed. Figure 5 illustrates the relative arrival times between tag and array for four untagged whales. Since the arrays did not have depth information, the actual location of the tagged whale is unknown, so the times are displayed assuming zero time lag between array and tag. For example, if the tagged whale were actually at 1.5 km slant range at time 200 s, there would be a 1 s difference between the presence of a tagged whales' sound on the tag and the detection of the same sound on the array, and all the curve data shown in Fig. 3 would have to be shifted vertically by 1 s, at the 200 s time. The complexity of the curves shown suggests that the availability of a tag acoustic record would permit high derivation of high-resolution movements of other animals. In effect, a tag combined with towed arrays could effectively track all vocalizing animals present on both the tag and array records.

## **IMPACT/APPLICATION**

The demonstration of the technique is expected to yield 1-3 trajectories per half-hour of recording time, if a group of animals is being followed. Over the course of a night (7 hours) one might reasonably expect to obtain at least 25 tracks, a credible sample size for studying variables such as dive descent time, maximum depth obtained, and the depth at which "creak" sounds begin. If controlled-exposure experiments are conducted on a separate set of nights, a data set for evaluating the effects of these sounds on dive descent time and depth might be extracted. The success of this algorithm would provide an inexpensive and rapid way of collecting statistically significant numbers of animal track for future environmental impact studies conducted by the division and other interested parties.

## **TRANSITIONS**

The algorithm will be tested between August 19 and September 12, 2002, in the Mississippi Delta and De Soto canyon regions, in conjunction with sperm whale tagging efforts by Mark Johnson and Peter Tyack, sponsored by the International Association of Geophysical Contractors (IAGC). During this cruise controlled exposures of whales to codas (sperm whale sounds associated with communication) and seismic

airgun signals will be conducted over several days, providing an ideal data set to test the algorithm performance and effectiveness in meeting long-term goals.

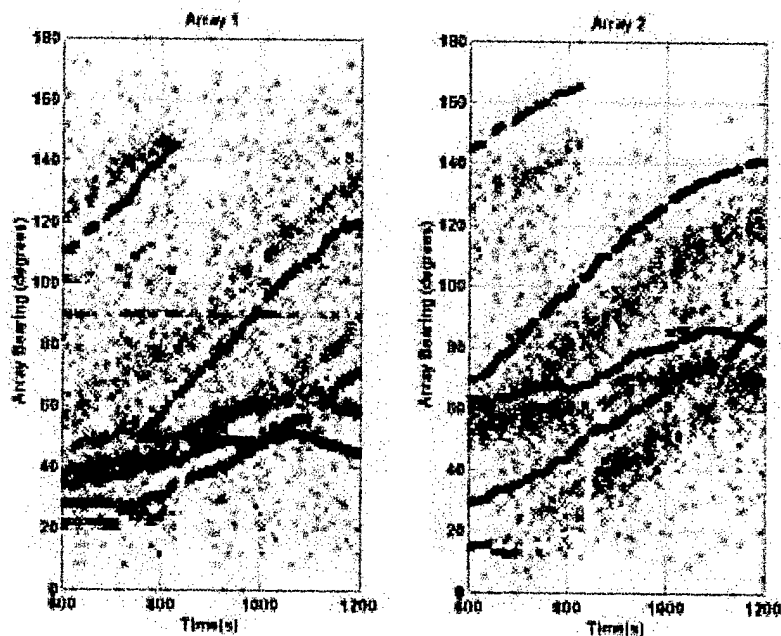
If the algorithm is found to be effective, it will be used to examine whether the diving behavior of an animal changes once it has been tagged, by following a single animal in the De Soto canyon area overnight to obtain multiple tracks, then tagging it in the morning.

## RELATED PROJECTS

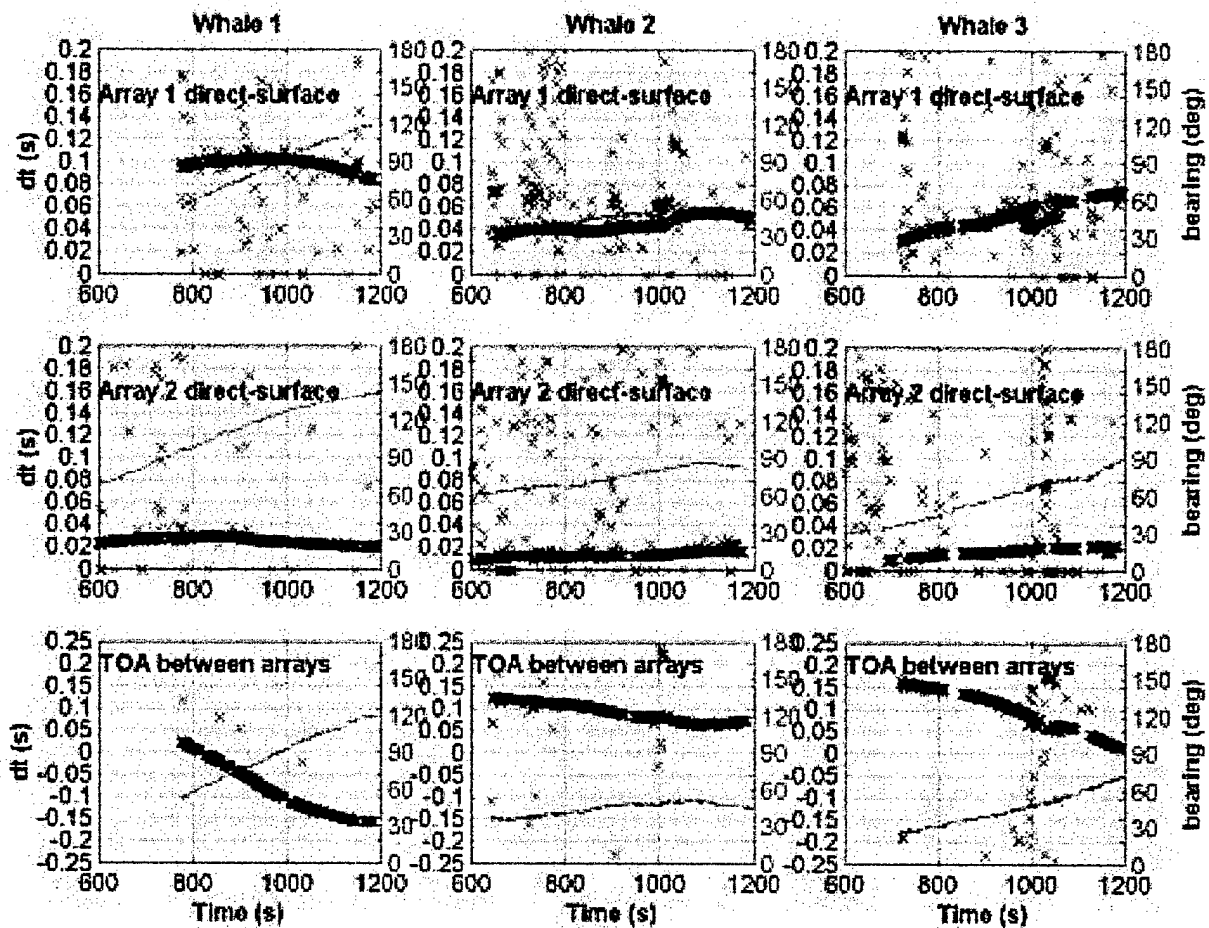
The Minerals Management Service has provided funding to continue this work, starting in June 2003.

## REFERENCES

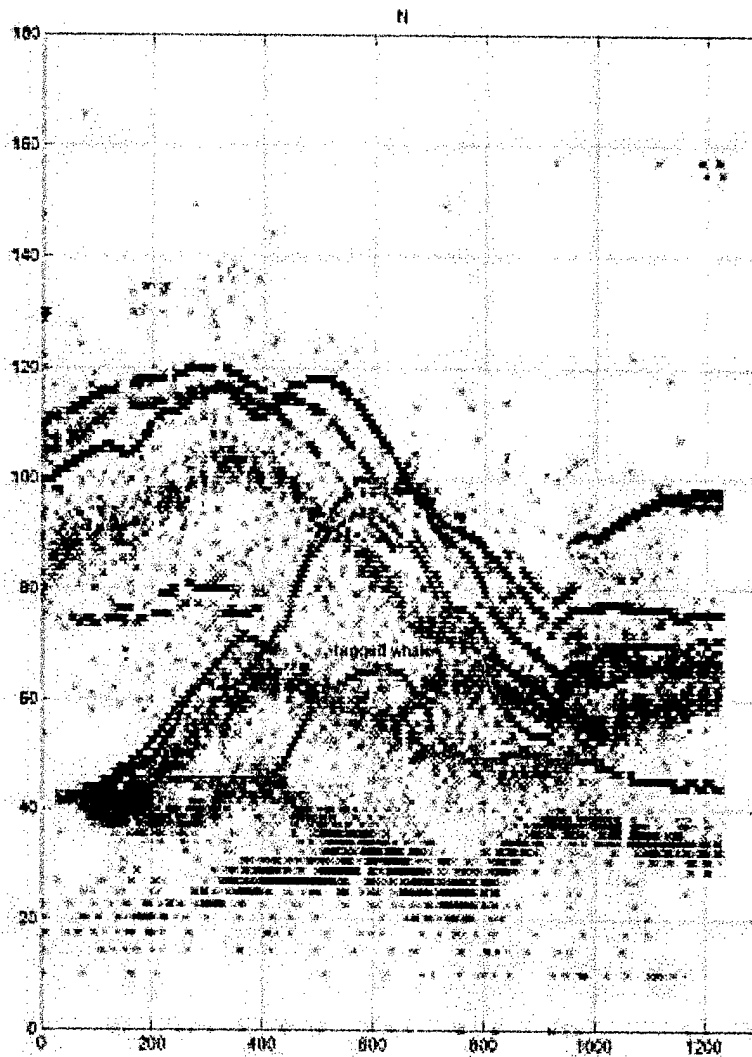
- [1] A. Thode, D. Mellinger, S. Stienessen, A. Martinez, and K. Mullin, "Depth-dependent behavioral and spectral features of diving sperm whales in the Gulf of Mexico," *J. Acous. Soc. Am.* **112**, 308-321 (2002).
- [2] M. Johnson, P. Tyack, and D. Nowacek, "A digital recording tag for measuring the response of marine mammals to sound," *J. Acoust. Soc. Am.* **108**, 2582-2583 (2000).
- [3] Mellinger, David K., "Ishmael 1.0 User's Guide," NOAA/PMEL, 2002.



*1. Bearings of four whales recorded on two serially towed arrays over a twenty minute period. Both direct and surface reflection bearings can be identified.*

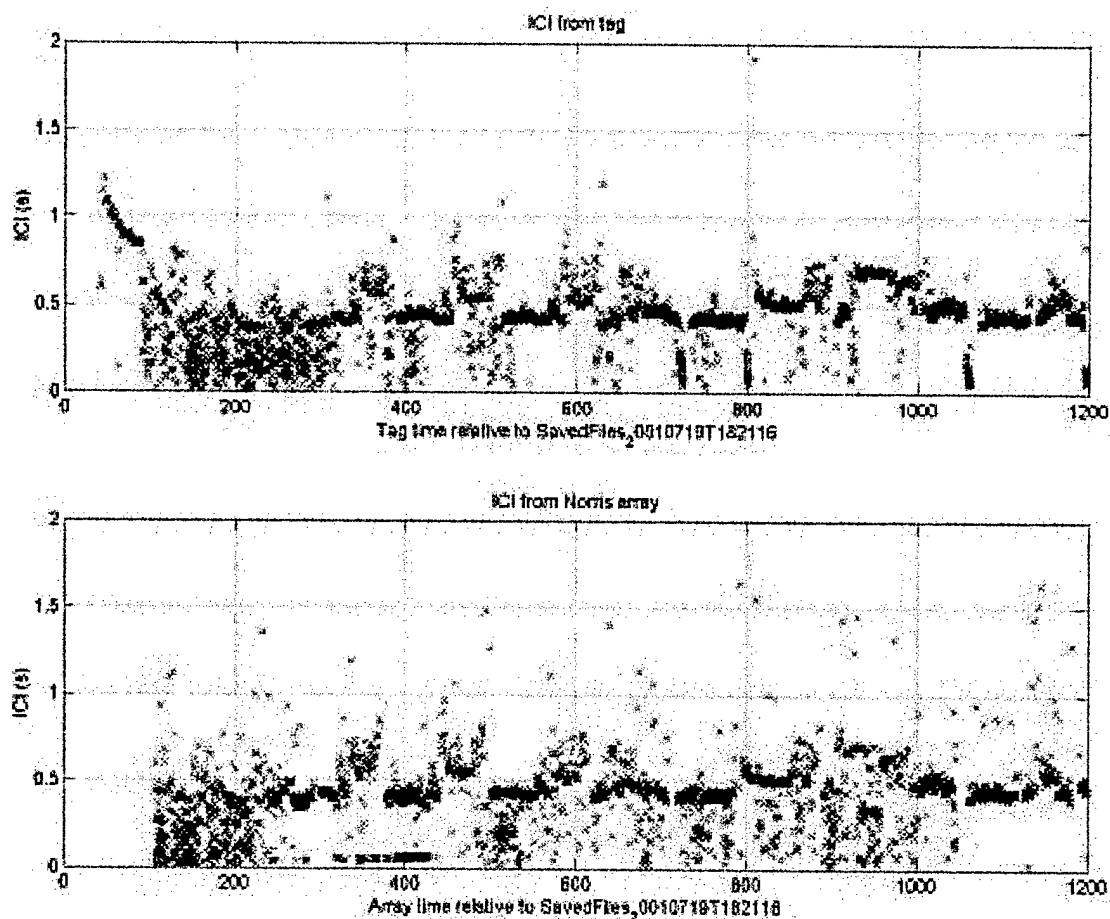


2. Localization information automatically extracted from tracks in Fig. 1. Each column represents a separate whale. Green lines are array bearings, to facilitate comparison with Fig. 1.

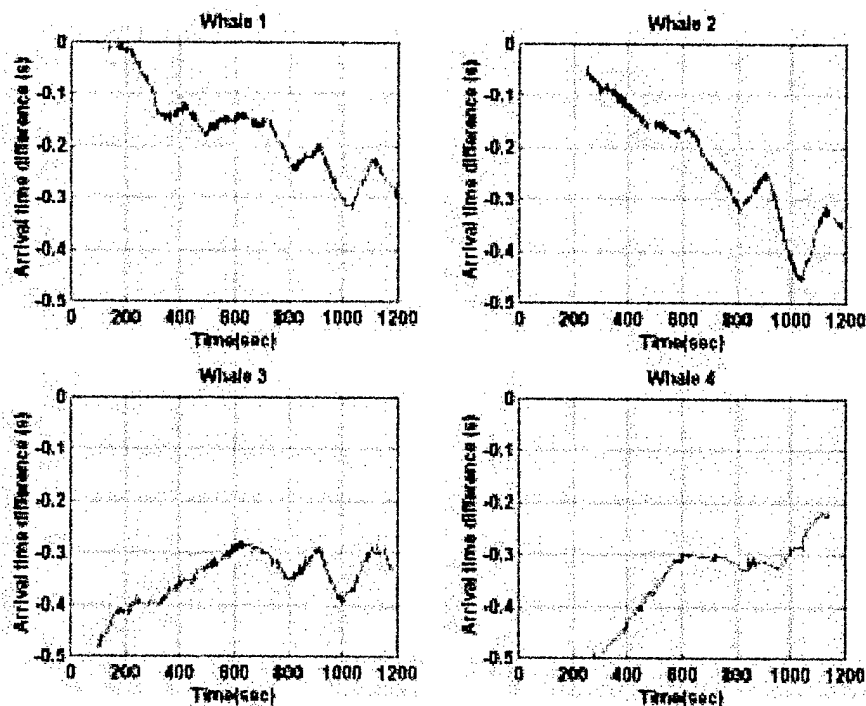


*3. Bearings of five whales recorded on one towed array over a twenty minute period, starting at 18:01 PM on July 19, 2001. Bearings of what turned out to be the tagged whale are labeled.. Red tracks are two whales believed to be associated with tagged whale.*





**4. Comparison of inter-click intervals (ICI). Top plot is derived from high-amplitude clicks in acoustic tag record. Bottom plot is derived from the bearing track labeled in Fig. 3. The similarity of the ICI pattern demonstrates that this is the same animal..**



*5. Illustration of how an acoustic tag on one animal can be used to track four other animals. Each graph represents arrival time differences between the tag acoustic record and the array, for sounds produced by each untaged animal. These figures have been constructed assuming no time difference between the tagged animal's own sounds on tag and array. If the location of the tagged animal were determined relative to the array vs. time, the curves here would be vertically shifted by the appropriate time-dependent amounts, and the locations of the four untaged whales determined.*

## PUBLICATIONS

[1] See Ref. 1 above.

[2] A Thode, D. Mellinger, Anthony Martinez, "Passive three-dimensional tracking of sperm whales using two towed arrays during the 2001 SWAMP cruise," submitted abstract, J. Acous. Soc. Am. Cancun Meeting, Winter 2002.

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